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CONTACTLESS PNEUMOGRAPHY OF SMALL LABORATORY ANIMALS AND A METHOD FOR QUANTITATIVE DETERMINATION OF THEIR PULMONARY VENTILATION

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Yu. N. Uspenskiy

Pneumography is used extensively both in experiments and in clinical-physiological examinations. From the pneumograms it is possible to assess the nature and regulation of external respiration under normal conditions as well as changes in the presence of various pathological conditions and under the influence of various agents on the organism. However, while in man and large animals the recording of respiratory excursions can be readily made, in small laboratory animals pneumography is technically difficult to perform and furthermore it involves immobilization of the animals which distorts normal breathing. Yet small laboratory animals are used the most to set up various experimental models of pathological processes (including those in the bronchi and lungs) and for dynamic investigation of respiratory functions under such conditions, which is extremely desirable.

At the present time, thanks to the development of contactless [remote] examination techniques (Luk'yanov, 1963; Luk'yanov, Solov'yev, 1963), it has become possible to perform pneumography on small laboratory animals (mice, rats, guinea pigs and others) with equal ease, while they are not immobilized. However the lack of equipment specially intended for this purpose restricts such examinations just as before.

For the recording of respiration of small laboratory animals we

GRAPHIC NOT REPRODUCIBLE

have adapted the existing clinical pulmocardiographic attachment, PK-1* which is equipped with a volumetric pickup and electromanometric trans-former.

This attachment is connected to an electrocardiograph (or any oscillograph) and through a rubber tube to a sealed 8 to 10 liter desiccator. The animal can move freely in it (Figure 1).

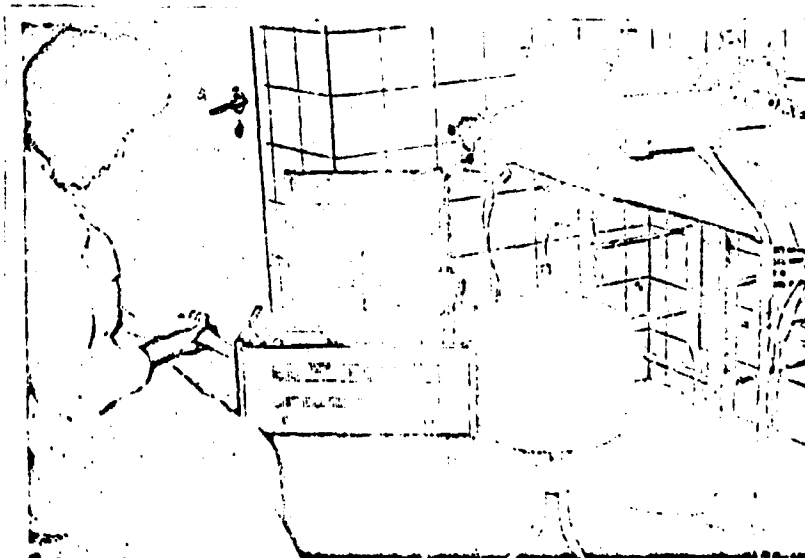


Figure 1. General view of the device for recording respiration of rats

One should have a desiccator or jar of larger volume (15 to 20 liters) to record respiration of larger laboratory animals (rabbits, cats). Fluctuations of pressure within the desiccator due to the animal's respiratory activity are picked up by the sensitive manometer and recorded on the electrocardiograph tape.

Concurrently we developed a technique for quantitative assay of pulmonary ventilation in animals which permits determining in relative values the minute volume of respiration as well as the depth and duration of each inspiration and expiration. Mathematical processing of the pneumograms expands information on the nature of changes of external breathing, and in dynamic studies it permits characterization of the

*The pulmocardiographic attachment manufactured by the experimental plant of the All-Union Scientific Research Institute of Medical Instruments and Equipment is designed for recording cardiac activity by recording pressure changes in the respiratory tract that are caused by cardiac contractions.

course and direction of a pathological process in the respiratory organs. As an illustration we submit a recording of respiratory excursions in different animals under normal conditions, and in rats suffering from pneumoconiosis (Figure 2). Experiments revealed that the shape of the curves, like the frequency and depth of respiration in all of the healthy animals are characterized by a strict pattern determined in many respects by species specificity and degree of age-related (anatomical-physiological) development of respiratory organs.

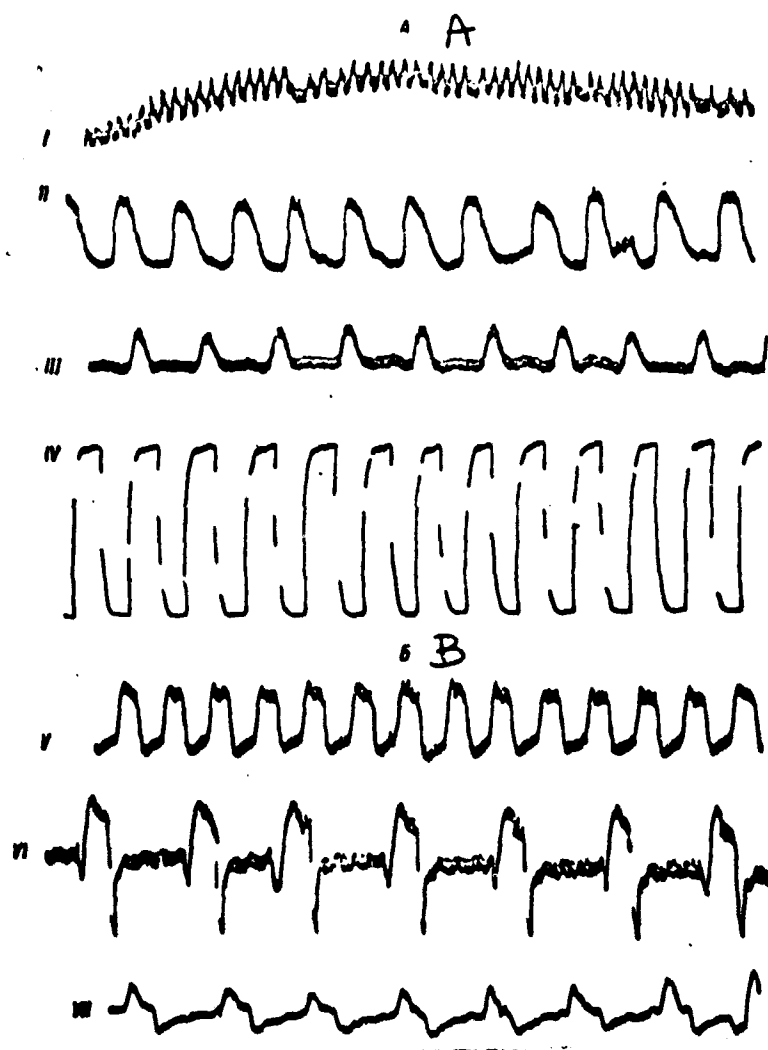


Figure 2. Pneumograms of different normal laboratory animals (A) and sick rats (B)

Legend:

I) mouse

II) rat

III) guinea pig

IV) rabbit

V, VI & VII) pneumograms of sick rats at different stages of pneumoconiosis

In sick animals (rats) the form of pneumograms and all other parameters of external respiration differ considerably from the normal, and they are directly related to the nature and severity of the course of the pathological process in the respiratory organs, as well as to the functional state and reactivity of the central nervous system. The latter is confirmed, in particular, by the respiration recordings of rats during deep anesthesia and reflex slowing of respiratory excursions upon inhalation of ammonia which has a strong irritant effect on the sensory endings of the trifacial nerve in the nasopharyngeal mucosal membrane.

In order to decode the pneumograms by the method we developed, the following is required: 1) determination of respiration rate (ω) for which, knowing the rate of movement of the tape in the recording device we count the number of respiratory waves per minute (as a rule pneumography is performed at a tape feeding rate of 25 mm/sec [millimeters per second]); 2) measurement (by the height of the respiratory waves) of the oscillatory index (h) for the subsequent determination of volumetric depth of inspiration or expiration; 3) standard of respiratory minute volume.

As the standard for rats we used the experimentally determined index of minute volume (Q) of 85 ml/min [milliliters per minute] at a respiration rate (ω) = 120 per min, and oscillatory index (h) equal to 5 mm with consideration of the instrument's calibration data.

When there is a change in rate and depth of respiration (related to age, functional load or pathology) the appropriate conversion is made on the basis of the given standard.

Examples

a) In rat No 1 the respiration rate (ω_1) is 150/min, the oscillatory index, $h_1 = 5$ mm. Consequently in order to determine the respiratory minute volume Q_1 of this rat the standard of minute volume Q must be multiplied by $\frac{\omega_1}{\omega}$ the degree of increase in respiration rate, $\frac{\omega_1}{\omega}$, i.e.:

$$Q_1 = Q \cdot \frac{\omega_1}{\omega} \text{ ml/min.}$$

Substituting the numerical values we will have:

$$Q_1 = 85.0 \cdot \frac{150 \cdot 5}{120 \cdot 5} = 106.25 \text{ ml/min.}$$

Thus, the minute volume of respiration in this rat was 21.25 ml/min greater than the standard.

b) In rat No 2 there was simultaneous increase in both rate and depth of respiration, namely, $\omega_1 = 150$ per min, $h_1 = 7$ mm. We determine

the volume of respiration (Q_I) using the equation:

$$Q_I = Q \cdot \frac{\omega_I \cdot h_I}{\omega \cdot h} \text{ ml/min}$$

or

$$Q_I = 85 \cdot \frac{150.7}{120.5} = 148.7 \text{ ml/min}$$

c) In rat No 3 there was slow respiration ($\omega_I = 90$ per min) and increase in depth of respiratory excursions (oscillatory index $h_I = 7$ mm). The minute volume of respiration (Q_I) equals

$$Q_I = Q \cdot \frac{\omega_I \cdot h_I}{\omega \cdot h} \text{ ml/min}$$

or

$$Q_I = 85 \cdot \frac{90.7}{120.5} = 89.25 \text{ ml/min.}$$

d) In rat No 4 there was decrease in amplitude of respiratory waves ($h_I = 3$) and acceleration of respiration ($\omega_I = 150$ /min). The minute volume of respiration will be:

$$Q_I = Q \cdot \frac{\omega_I \cdot h_I}{\omega \cdot h} \text{ ml/min}$$

or

$$Q_I = 85 \cdot \frac{150.3}{120.5} = 63.7 \text{ ml/min.}$$

etc.

Our studies revealed that in healthy rats of average weight (200 to 250 grams) at rest, the minute volume ranges from 70 to 110 ml per minute, or 4200 to 6600 ml/hour. The mean respiration rate is 110 to 150/min, which is consistent with the data of I.P. Zapadnyuk et al (1962).

In order to determine the volume of a single respiratory excursion (one inspiration or expiration) the minute volume of respiration has to be divided by the number of respiratory excursions per minute.

Electrocardiographs (oscillographs) may have different calibration indices, therefore before using them they must either be adjusted or determination must be made of the corresponding correction index. In order to determine the latter respiration must be recorded on at least ten healthy animals of the same age and same standard weight (200 grams) and determination must then be made of the arithmetic mean value of the

oscillatory index. The correction index (K) will equal the ratio of the standard oscillatory index ($h = 5$ mm) to the one obtained. For example, if the obtained value of h will be smaller than the standard, let us assume 3 mm, then

$$K = \frac{5}{3}, \text{ i.e. } 1.67;$$

if it is greater, let us assume $h = 7$ mm, the correction $K = \frac{5}{7}$, i.e. 0.71. In such cases the basic calculating equation will be

$$Q_1 = K \cdot Q \cdot \frac{\omega_1 \cdot h_1}{\omega \cdot h} \text{ ml/min.}$$

In addition to determination of the above parameters the following are also important: duration of inspiration and expiration (measured in seconds), normally in rats expiration lasts 1.5 to two times longer than inspiration; duration of the pause between expiration and inspiration (in the normal rat the pause lasts 0.12 to 0.15 seconds);* the value of the plateau (if it is present) at inspiration and expiration (in mm) indicating breath holding and, as we have already mentioned above, the form of the pneumogram pattern which is of diagnostic value, and in rats as well as in large animals it varies, namely: dome-shaped, triangular, mixed, plateau, sharp-concave-convex, staggered, arrhythmic. The first three characterize normal respiration and are evidently determined by individual anatomical architectonics of the chest and respiratory tract, and the others are observed in the presence of various pathology of respiratory organs, for example: plateaus in the presence of emphysema, sharp-convex-concave with local or diffuse bronchial obstruction (non-patency), etc. The general conclusion on the condition of respiratory organs is made according to the set of indices and changes observed in the course of dynamic studies.

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*In comparing these values on different pneumograms one can use the length of the corresponding segments of pneumograms (in mm) rather than the true magnitude (in seconds). And the tape feeding rate must be taken into consideration.